Space Launch Vehicles Broad Area Review Report Nov 1999

Outline

- Charter
- Overarching Issues
- Fly-out Programs
- Transition to Evolved Expendable Launch Vehicle (EELV) Families
- Summary
- Appendices
 - A. Summary of Recommendations
 - **B. BAR Organization and Participants**
 - C. Failures and Anomalies
 - D. Quality Assurance, Independent Review, and Engineering
 - E. Boeing and Lockheed Martin Independent Review Summaries

Charter

Establish a Broad Area Review (BAR) to:

- Examine recent launch failures
- Provide a report that includes
 - Causes of the failures
 - Recommendations for changes in practices, procedures, and operations to enhance mission success

BAR limited its review to space launch vehicle activities up to and including spacecraft separation on orbit

Scope of BAR Investigation

Addressed

- Atlas, Delta, Titan (including Centaur and IUS upper stages) & EELV families during transition
- Range of participants in the launch cycle (USAF, NRO, NASA, DCMC, FFRDC, SETA, contractors)
- Launch activities since 1985

Not addressed

- Foreign launch systems
- Emerging commercial expendable and reusable systems
- Spacecraft post-separation operations and on orbit failures
- EELV end state

Two Overarching Issues

- Mission success in fly-out of current (Titan, Atlas, Delta) systems -- approximately \$20B in launch vehicle and spacecraft assets -- includes critical systems with no spares
- Transition to the future systems -- Evolved Expendable Launch Vehicle (EELV) families -building confidence in launch success

Fly-Out Programs

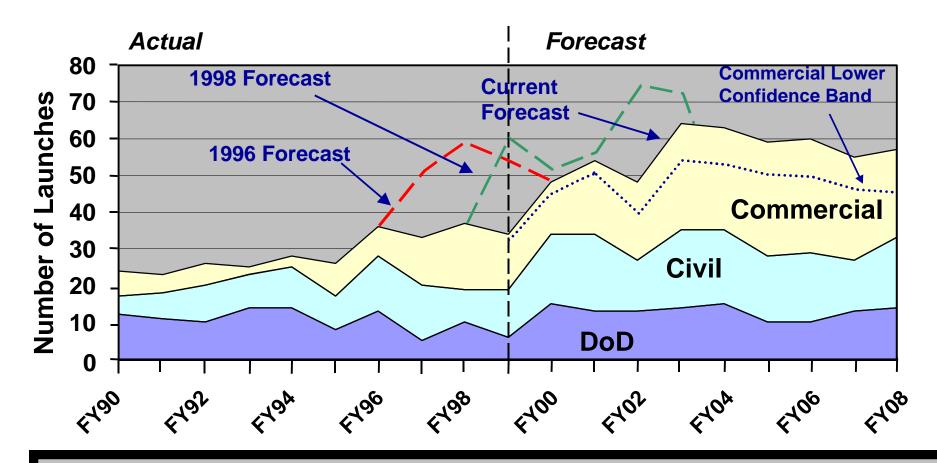
Key Observations -- Fly-out Programs

- Approximately \$20B in assets are at risk on Titan, Atlas and Delta flyout missions (39 vehicles) -- includes critical systems with no spares
- Titan and Inertial Upper Stage (IUS) programs exhibit a premature "going out of business" mindset
- Approach to fly-out systems is influenced by EELV anticipation
- System design and process engineering deficiencies played a prominent role in failures and near misses -- program management
- Clear authority and accountability for delivering DoD spacecraft on orbit is key to increased mission success
- Maintaining engineering and technical support expertise is critical to mission success for these programs
- Given the historical record, satellite constellation planning and budgeting based on 100% launch success (no spares) is unrealistic

Key Observations -- Titan

- Titan IV missions remain complex, high value and "one-of-a-kind" warranting special attention to maximizing potential for mission success
- Based on past experience, the Titan fly-out will be extended by at least a year
- At this point in the Titan program, the potential for cost savings is minimal when compared with the value of the assets at risk
 - Potential cost reductions less than 2% of cost of assets at risk
 - For "cheaper, better, faster" in space launch, the route to true "cheaper" is "better" -- high reliability

Launch History and Forecasts Total U.S. Space Launches -- Quantity of Launches



Bow wave continues to shift to the right Forecast indicates government will remain a prominent player

Sources: National Launch Forecast, Space Launch Manifest, NASA Forecast, SV and LV Contractor Manifests, Space Launch Information Center

Fly-out Context

- Atlas, Delta and Titan launched 777 space missions since 1958
- Established national security satellite constellations for:
 - Communications
 - Missile early warning
 - Weather
 - Navigation
 - Reconnaissance and surveillance
 - Experimentation
- Provided the foundation for the U.S. commercial launch industry
- Contributed to NASA's space science and planetary missions and early manned space flight

Failures & Serious Anomalies

- Atlas/Delta/Titan launch vehicles
 - One failure per year (average) during past 12 years (200 launches)
 - Five failures (Delta III, Titan IV) in 10 months (25 launches)
 - Upper stages -- 3 failures (5 launches)
- Serious Atlas/Delta/Titan anomalies e.g., major leak, bad separation, nozzle loss
 - 18 in past 12 years (200 launches)
 - 9 in 24 months (51 launches)

Recent Failures

Government Missions

- Titan IV A-20/Centaur/NRO
 - Titan wiring harness caused short -- damaged pre-launch
- Titan IV B-27/Inertial Upper Stage-21/DSP-19
 - IUS thermal tape misapplication restricted separation connector operation -- indications present in previous flights
- Titan IV B-32/Centaur TC-14/Milstar-3
 - Centaur manual data entry error in flight software -- resulting anomaly detected pre-launch but not corrected

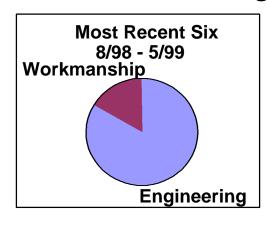
Commercial Missions

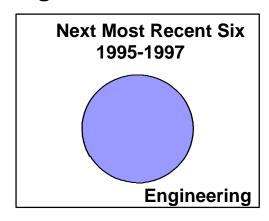
- Delta III 259/Galaxy-X
 - Inadequate modeling of flight control dynamics
- Delta III 269/Orion-3
 - Inadequate brazing specification potentially coupled with vehicle induced loading caused combustion chamber breach

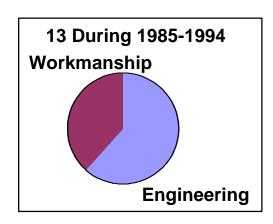
Factory-introduced engineering and workmanship errors predominate

Failure and Major Anomaly Causes

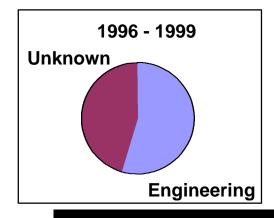
Failures -- 76% Engineering

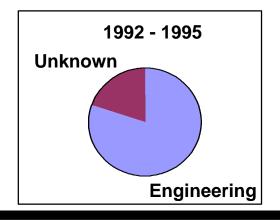


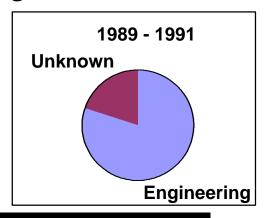




Major Anomalies -- 69% Identifiable as Engineering







- Engineering deficiencies prominent in majority of mishaps
- Space launch remains an intensely engineering activity
- Inadequate post flight analysis of anomalies

Some Current Launch System Facts of Life

Titan IV system launches

- Remaining 11 launches involve high value national security spacecraft (~\$9 Billion)
- Are demanding -- will never be routine
- Each configuration is unique
- Almost no margin for error
- Infrequent events -- e.g. Titan/IUS had 1 launch in 4 years (1994-1998)
- Launch schedules inevitably move to the right -- often significantly

• Even Atlas and Delta, with a string of launch successes, generate continuing unique challenges

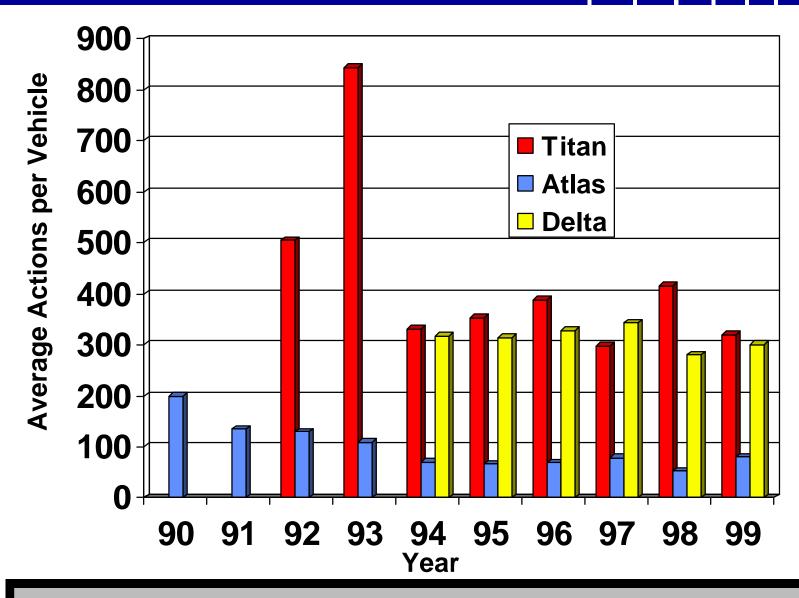
- Atlas and Delta experienced 8 major anomalies in last 2.5 years
- Atlas 141 has been on Pad 3E at Vandenberg for more than two years due to spacecraft and upper stage issues

Titan Development

- 1960s -- Air Force started heavy lift space booster program using Titan II upgraded to Titan III
- 1978 -- decision to fly all DoD, civil and commercial spacecraft on the Space Shuttle ended the Atlas, Delta and Titan 34D programs -based on economics
- 1983 -- Air Force initiated the CELV program to back up the space shuttle -- continue a Titan/Centaur line for 10 additional launches
- 28 January 1986 -- Challenger accident
 - Unmanned missions to be on ELVs
 - The U.S. expendable fleet was reborn
 - Titan program redefined with multiple configurations & launch sites
- June 1989 -- first launch of the 41-buy Titan IV

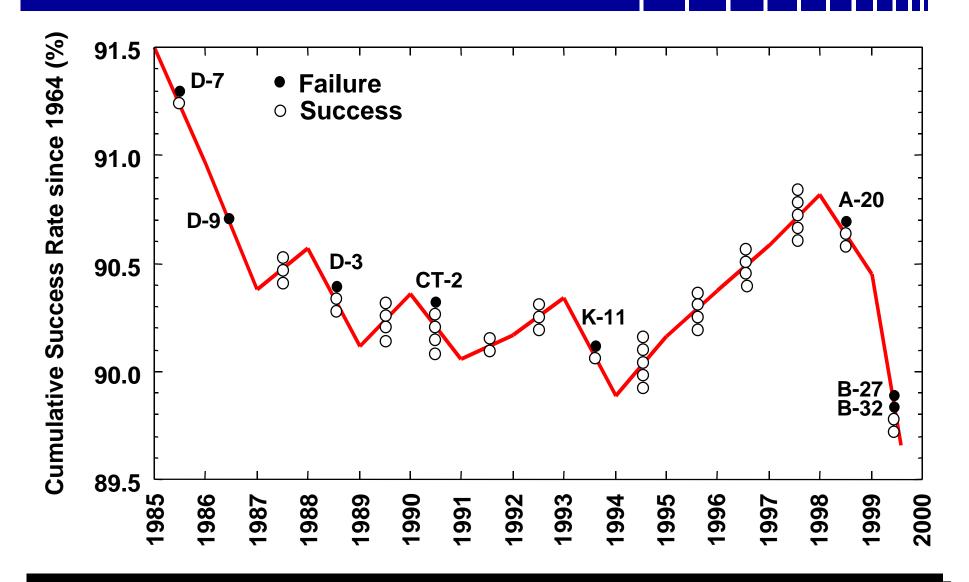
Titan IV acquisition reflects emergency response to accommodate spacecraft from Shuttle

Manufacturing Discipline Launch Base Unplanned Work



Ninety percent of unplanned Titan work to correct factory errors

Titan Success Rate History



Mission success planning needs to reflect launch reliability reality

From Oversight-Insight to Partnership

"Partnership in Confidence Building"

Oversight:

Using government resources to monitor <u>all aspects</u> of contractor performance in product delivery and execution of approved processes

Insight:

A customer's risk-based understanding, validation, and surveillance of a supplier's management <u>systems</u> and process performance <u>metrics</u> to assure product quality and contract compliance"

Partnership:

A knowledgeable, involved customer using prudent risk management while participating in <u>developing the confidence</u> needed to entrust unique, high value spacecraft to a launch system

NASA Approach For Mission Success

Clear accountability for mission success

 Launch vehicle acquisition/mission success responsibility in single organization at Kennedy Space Center

Mission requirements

- Majority of spacecraft are one of a kind
- Variable levels of mission complexity

Consistent mission success process for all ELV missions

- Process for tailoring technical oversight
- Spacecraft assignment policy includes assessment of launch vehicle flight history and mission criticality/complexity/value
 - Cat 2: medium-cost, mission critical spacecraft: NASA will not fly first insight/oversight
 - Cat 3: high value, mission critical spacecraft: seek 14 consecutive successful flights <u>insight/oversight</u>

DoD/NRO do not have the option to adopt the full NASA approach -- can use important elements

Finding and Recommendation Fly-out Programs -- Program Management

- Failures and major anomalies reflect the need for contractor program management to provide more disciplined systems engineering in design and processes
 - Contractor Independent Reviews strongly support this finding
 - If this were done as well as all would like, all else would follow
 - Contractors have laid out a comprehensive program to improve

Recommendation

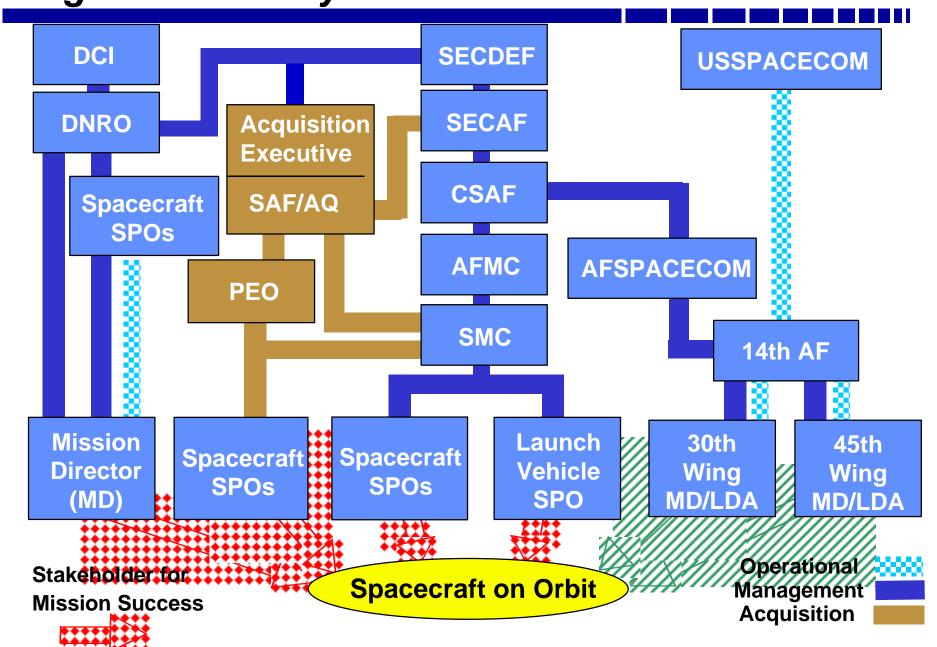
 Air Force rigorously track contractor actions to focus program management on disciplined systems engineering and processes and implementation of corrective actions resulting from failures and Contractor Independent Reviews

Findings -- Fly-out Programs Management -- Organization

- Government launch mission success roles and responsibilities are fragmented across AFMC (SMC), AFSPACECOM, SAF/AQ and industry
 - Authority, responsibility and accountability are not linked and handoffs are not well defined
- Mission Director role not clearly defined in all cases

There is an urgent need to clearly identify authority and responsibility for delivering spacecraft on orbit

Authority and Responsibility for Delivery on Orbit -- Fragmented Today



11/5/99

Responsible for Launch Processing,

Launch Commit and Range Go/No Go

Space Launch vs. Aircraft Systems

- Space launch has important similarities and differences when compared to aircraft systems
 - Key similarities -- need for
 - Acquisition system clearly responsible for delivering an operational asset to the operational customer
 - Clearly defined hand-off -- acquisition to operations
 - Operational involvement in acquisition
 - Continual feed-back of lessons learned into policies, procedures and engineering
 - Key differences
 - Launch is highest risk phase of the space system life cycle
 - Launch of heavy lift systems for high value spacecraft unlikely to become routine -- clearly not with fly-out systems
 - Greater demand for engineering expertise and support from cradle to grave
 - Space launch reliability not verified by a flight test program
 - Initial flights often carry operational spacecraft
 - Flight experience -- minutes vs thousands of hours
 - Limited post flight data

Some Underlying Assumptions and Principles for Organizing Responsibility for Delivery on Orbit

- The Government will maintain the responsibility and liabilities for launch vehicles, spacecraft and delivery on orbit to the user.
 - The customers for on orbit delivery are US Space Command and the intelligence community
 - The operators of DoD on orbit systems are US Space Command components and NRO
- For the foreseeable future, the Air Force will have responsibility for sustaining the basic launch base and range infrastructure and support capability.
 - AF Space Command will continue to exercise this responsibility

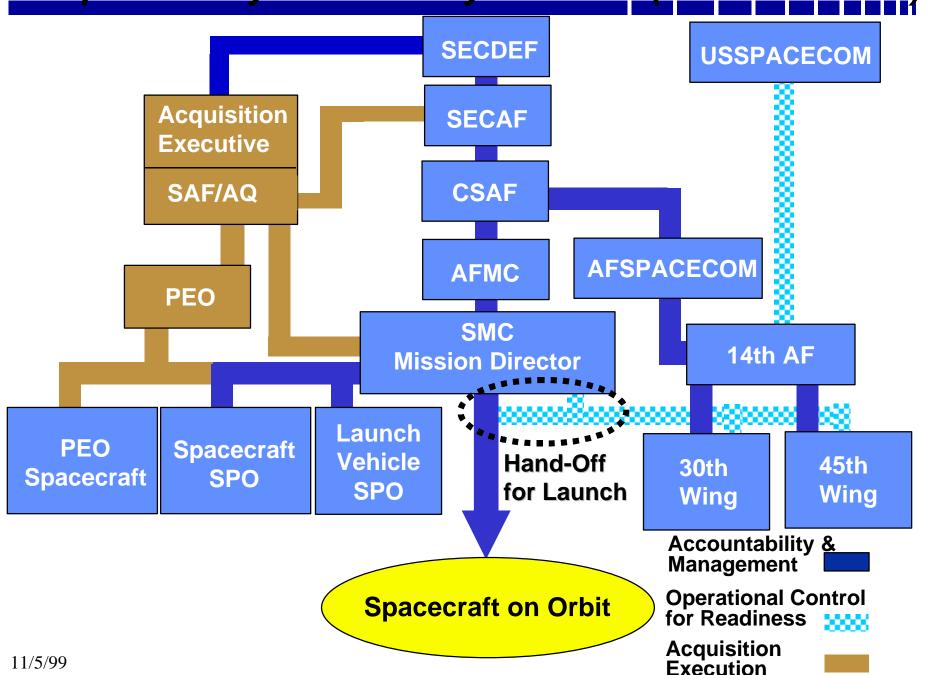
Recommendation -- Fly-out Programs Management -- Organization

Recommendation

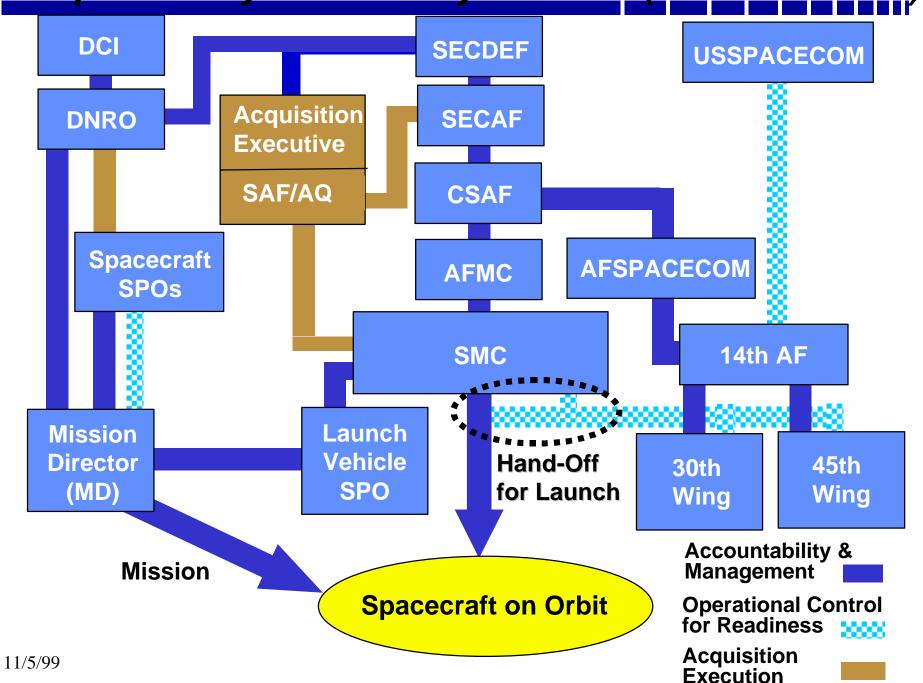
- SECAF and CSAF assign clear responsibility, accountability and authority to the acquisition command for all launch vehicle activities through delivery of spacecraft on orbit (separation from the launch vehicle)
 - Make Space and Missile Systems Center (SMC) responsible for assembly and certifying readiness to launch (on the pad) -engineering responsibility retained through delivery on orbit
 - SMC/CC names Mission Director for DoD missions*
 - AFSPACECOM supports SMC in launch base activities and retains launch decision authority, safety, and range responsibilities -- conducts the launch after SMC certification

^{*} DNRO names Mission Director for NRO missions

Fly-Out Programs -- Needed Authority and Responsibility for Delivery on Orbit (DoD Missions)



Fly-Out Programs -- Needed Authority and Responsibility for Delivery on Orbit (NRO Missions)



Findings & Recommendation -- Fly-out Programs Schedule and Resources

- Titan and IUS programs exhibit a premature "going out of business" mindset
 - Chronically understaffed and personnel allotments decreasing
 - Maintaining management, technical and engineering oversight expertise is becoming increasingly difficult in both government and industry
- Based on past experience and the lack of schedule margin, there is a high probability that Titan fly-out will be extended at least a year
 - Today, virtually no schedule margin for 11 launches
 - Since 1995, 12 of 17 launches have been more than 70 days late,
 2 have launched within 2 days of schedule

Recommendation

 SECAF direct that AFSPACECOM and SMC produce a realistic launch schedule and funding profile

Findings -- Fly-out Programs Risk Management

- Formal risk management policies, practices and procedures have been degraded over the past decade
 - SMC Commander's Policies cancelled/not enforced by SAF/AQ
 - No formal technical risk management process
- Institutionalized approach needed to reduce failures and anomalies
 - Lack of formalized sharing of information across all programs (government and commercial)
 - Inadequate post-flight analysis -- needed for continual reliability improvement

Recommendations -- Fly-out Programs Risk Management

Recommendations

- Air Force institutionalize a formal launch risk management program
 - Develop and manage a risk management plan for all fly-out systems
 - Emphasize identifying and mitigating risks
 - Formalize systems engineering and quality policies, practices and procedures
 - Re-institute a comprehensive post-flight analysis program
- Air Force make SMC/CC responsible for timely, formalized mechanism to capture and disseminate lessons learned across programs and contractors

Findings -- Fly-out Programs Systems Engineering and Engineering Review

- Engineering process and workmanship are both prominent in mishaps since 1985 -- historically consistent themes
 - Lack of disciplined system engineering in design and processing of launch vehicles
 - Lack of communication of critical data
 - Inadequately defined processes
 - Inadequate review process -- particularly in design and design change
- Actions have been initiated that begin to dismantle the government oversight capability with extensive fly-out to complete
 - The challenge of mission success in fly-out systems has not declined -particularly Titan IV with upper stages
 - FFRDC and in-house Air Force engineering support have been reduced by 50% and 66% respectively in the past five years
 - The Titan contractor has followed a similar trend and made reductions in quality and engineering functions

Findings -- Fly-out Programs Systems Engineering and Engineering Review (cont'd)

- SMC and DCMC need to significantly strengthen technical support to complete fly-out programs
 - DCMC reductions weakened SPO's ability to monitor in-plant activities
 - Mandated reductions of technical personnel -- impact on mission success not adequately assessed
 - SMC engineering staff and FFRDC cuts limit oversight capability -- heaviest losses in most experienced engineers
 - Currently programmed for further reductions
- Effective Independent Review has eroded
- Properly conducted Independent Review remains essential to mission success
 - Greatest return during engineering design
 - Continued Independent Review has value throughout the life-cycle

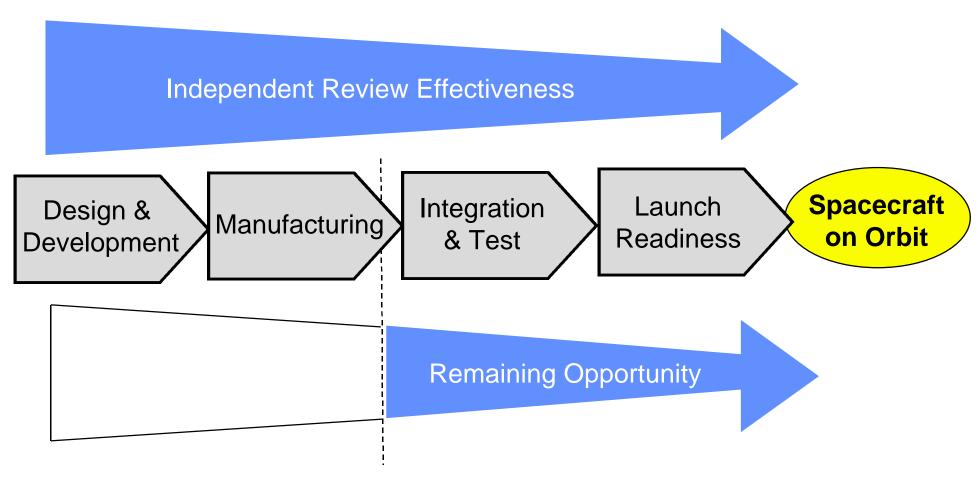
Space launch is inherently more engineering intensive than other operational systems

Recommendations -- Fly-out Programs Systems Engineering and Engineering Review

Recommendations

- Reverse the draw-down in engineering support now
 - SMC/CC identify engineering support needs (SPO, FFRDC, DCMC), consistent with the realities of the special nature of the fly-out programs and report requirements to the SECAF within 30 days
 - SMC/CC return to full Independent Reviews vice current approach of sampling identified risk areas
- Air Force request DCMC increase in-plant technical support
- Air Force increase launch base technical manpower commensurate with fly-out risk and maintain through transition period of EELV program

Recommendation-- Fly-out Programs Independent Review



Recommendation

 SECAF direct SMC/CC to identify remaining opportunities and resources needed for value added government Independent Review

Findings & Recommendations -- Fly-out Programs Titan Cost Pressures

- Cost pressures adversely influenced mission success
 - Air Force and contractor responses to long-standing government concern over high cost of Titan
 - Reductions in mission success staff, engineering attention, and technical oversight
 - Savings assumed in planning for execution
 - Findings also confirmed by contractor Independent Assessment Team
- Seeking marginal cost reductions in launch, the highest risk phase of the life cycle of a space system, is not likely to produce either "better" or "cheaper"

Recommendation

 Use straightforward mission performance incentives designed to properly balance the pervasive cost pressures

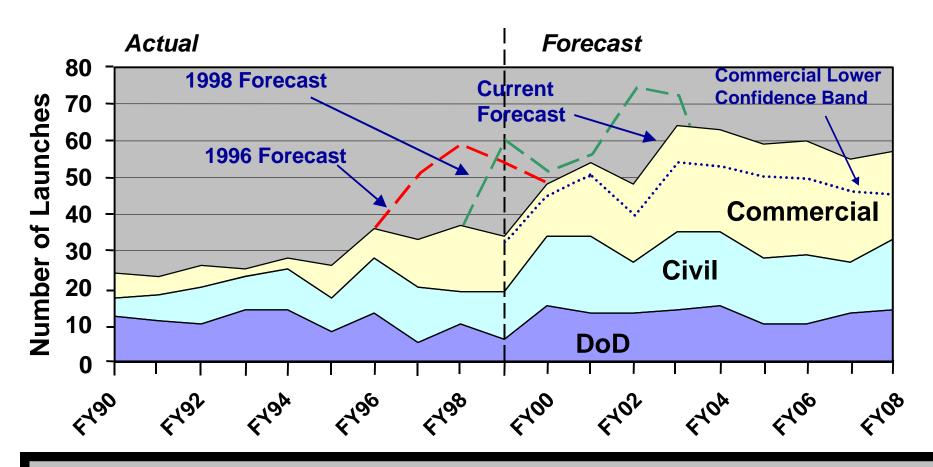
Transition to EELV Families

Key Observations -- Transitioning to EELV

- The nation's future access to space depends on successful transition from the fly-out systems to the families of EELVs.
- In the EELV era, launch will remain the highest-risk aspect of missions in space -- most launch systems have experienced startup failures
- The BAR was unable to discover a definition of the planned end state for EELV support of DoD and NRO payload requirements nor a detailed and disseminated plan for transition to EELV
- It has not been defined who will be responsible for delivering a functioning spacecraft on orbit
- The current EELV contracts do not provide mission success incentives

DoD needs to be a smart, more involved customer

Launch History and Forecasts Total U.S. Space Launches -- Quantity of Launches



Bow wave continues to shift to the right Forecast indicates government will remain a prominent player

Sources: National Launch Forecast, Space Launch Manifest, NASA Forecast, SV and LV Contractor Manifests, Space Launch Information Center

Findings - EELV Transition Strategy Update -- Program Evolution

Nov 97 Acquisition Strategy

Launch market dominated by commercial market

Tremendous growth potential in commercial market

Two EELV families/contractors

Conclusion: sufficient market to support two EELV concepts

Recommendation: Share development costs between government and commercial

Reliability maturation through commercial launches

BAR Assessment of Today (Oct 99)

Government remains a dominant customer

Commercial market potential uncertain

Expanding EELV families

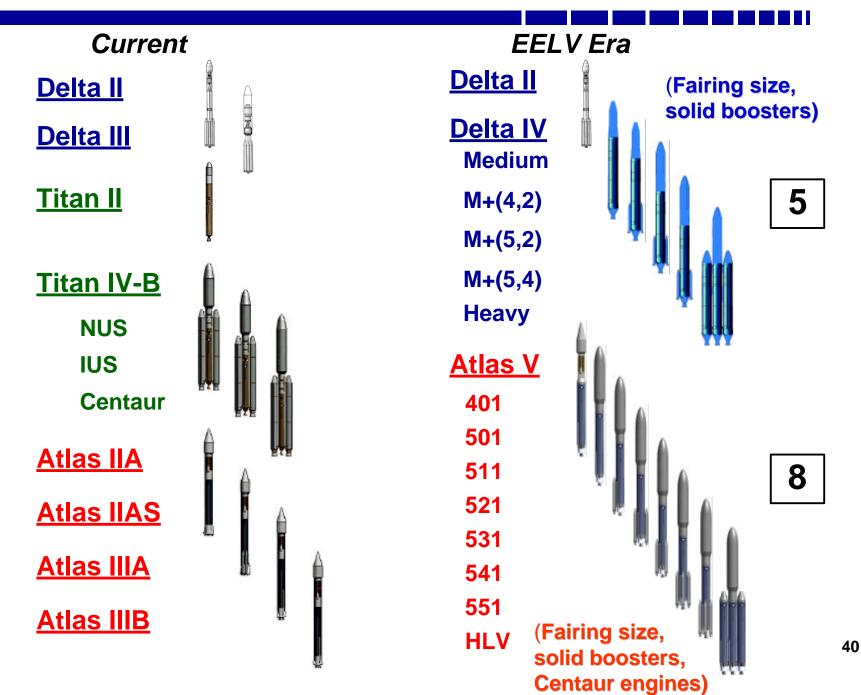
Conclusion: corporate cost pressures -- less certain ROI

Recommendation: Partner with industry to gain confidence in reliability

High probability govt. first to fly on heavy EELV and a variant of medium EELV

Not prudent for government to assume that the commercial marketplace will establish confidence in EELV reliability for early government launches

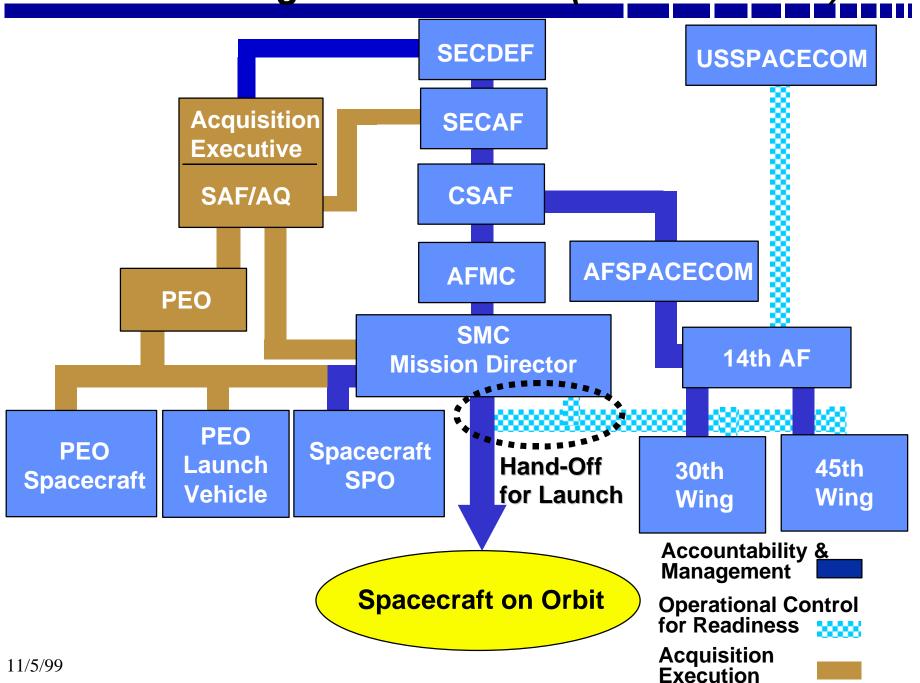
Launch Vehicle Configurations



EELV Mission Success Accountability -- Options for Delivery on Orbit

- The current approach -- government accountable, but limited ability to verify
 - Government-contracted launch service -- launch contractor builds and launches with minimal government oversight
 - Option dependent on assumptions that are no longer valid
- Modified current approach -- government re-engages as a smart, more involved customer
 - Government provides <u>prudent oversight as a partner</u> while building confidence in reliability and reducing risk for high-value missions
- Commercial approaches -- spacecraft contractor accountable to government
 - Government buys spacecraft on orbit
 - Spacecraft contractor-furnished spacecraft and launch service -- subcontracts for launch services
 - Government buys service on orbit
 - Spacecraft contractor-furnished data from orbit -subcontracts for launch services

EELV -- Authority and Responsibility Options Prudent Oversight as a Partner (DoD Missions)



Findings - EELV Management

- Government plan for the EELV end state and transition from heritage systems to EELV is incomplete and not disseminated
- The DoD organization that will have authority, accountability and responsibility for delivering spacecraft on orbit needs to be heavily involved now in development of transition planning
 - EELV program needs to incorporate clear authority, responsibility and accountability for delivering spacecraft on orbit

Recommendations - EELV Management

Recommendations

- SECAF assign clear government responsibility, accountability and authority to SMC/CC for delivery of spacecraft on orbit
 - Ensure adequate engineering resources are made available
- Air Force complete and widely disseminate an end state and transition plan that lays out the management approach and the approach to building confidence on the front end of the EELV program
 - Ensure lessons learned from heritage programs are applied to EELV
- SAF/AQ and AFMC program resources, including engineering and other support staff to meet needs of transition

Findings -- EELV Partnering

There needs to be a joint government-industry understanding on:

- detailed technical baseline including design, build, and testing
- simulation and analysis, qualification, "test like you fly", and
 IV&V baselines
- mission success enhancements/investments required to maximize confidence in EELV during start-up and transition to a fully mature system

The government needs clear visibility into:

- progress toward meeting the technical and IV&V baselines
- change control process

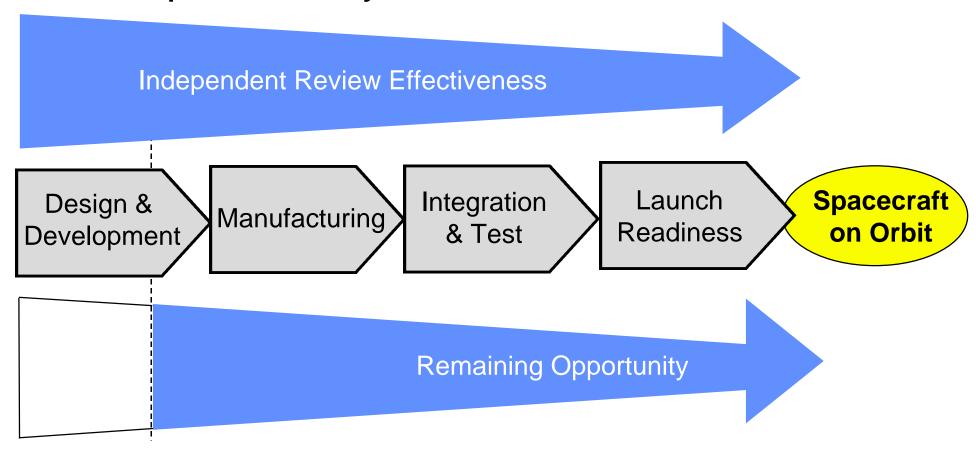
Recommendation -- EELV Partnering

Recommendation

- SECAF provide direction to develop and implement a joint government-industry plan for a "value-added" government role as a smart and involved customer that addresses:
 - Technical participation during the development of EELV configurations
 - Building confidence in launch reliability

Findings & Recommendation -- EELV Independent Review

 Needed government involvement in review of design and development is already late



Recommendation

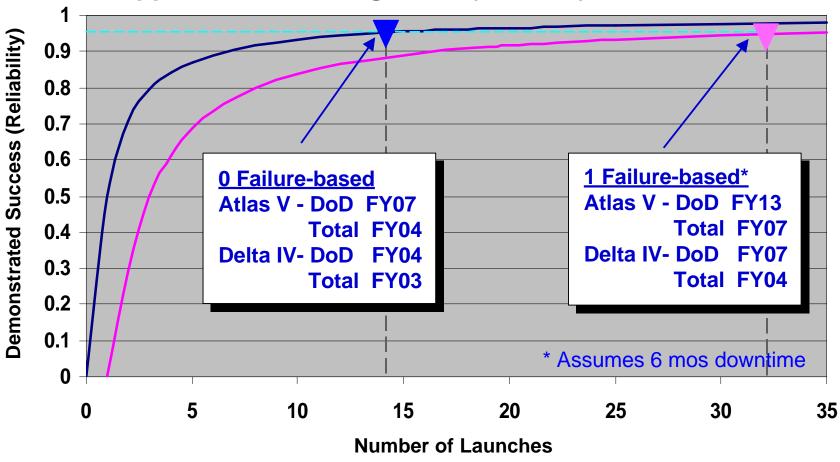
 SECAF direct SMC/CC to identify opportunities and resources needed for value added government Independent Review

Findings -- EELV Building Confidence in Reliability Expectations

- The planned EELV family is a multi-configuration system with multiple variants
- Design goal for EELV is 98% -- demonstrated heritage reliabilities vary between 90-95%
 - Atlas, Delta, Titan experienced start-up anomalies -- a number of successful flights will be required to demonstrate projected reliability
 - It is prudent to expect that the EELV family will need a period to mature and demonstrate reliability
- Risk management process for development and operations of EELV is a critical issue and needs a well defined plan for mission success
- Whatever the management approach selected, spacecraft value demands that DoD be a smart, more involved customer
- A government commitment to reliability investment will be needed to bring confidence in EELV reliability up to the point of prudent risk for DoD high value and often unique spacecraft
- Additional Government investment will help commercial competitiveness and lower the overall space systems costs to the government

Findings -- EELV Building Confidence in Reliability Expectations (cont'd)

Current approach to building EELV (Medium) launch confidence



Illustrates the time period for each EELV family to demonstrate reliability - at 50% confidence using launch experience

Launch estimates based on: National Launch Forecast, Space Launch Manifest, NASA Forecast, SV and LV Contractor Manifests, Space Launch Information Center

Findings -- EELV Building Confidence in Reliability Expectations (cont'd)

- The government will bear the brunt of establishing early confidence in reliability during the transition
 - Design discipline & margins
 - Early Independent Review
 - More testing & verification
 - Effective failure and anomaly analysis
- Requires technical oversight and risk management

Recommendations -- EELV Building Confidence in Reliability Expectations

Recommendations

- Air Force formulate a formal EELV launch risk management program
 - Develop and manage a risk management plan for EELV systems
 - Formalize systems engineering and quality policies, practices and procedures
 - Develop and implement an improved mission assurance process based on the best attributes of SMC, NASA and NRO mission assurance practices
- SECAF ensure robust engineering support until launch reliability is demonstrated
 - Task SMC/CC to provide a revised estimate of government engineering support requirements within 30 days

Recommendations -- EELV Building Confidence in Reliability Expectations (cont'd)

Recommendation

- USD(A&T) and SECAF consider investment to accommodate needed reliability confidence-building (both contractors) to provide:
 - Added launch vehicle redundancy and built-in-test diagnostics
 - Heavily instrumented early verification flights of medium and heavy lift configurations to verify models and simulations
 - Use new micro-technologies to enhance instrumentation
 - Government verification of qualification levels and design analyses at the component level for early launches
 - Additional system level testing to reduce "qualification by similarity" and interaction risks
 - Captive test firing of appropriate EELV configurations

Findings -- EELV Cost Pressures

- Heavy cost pressure is built into the EELV program -- criterion is 25% (with a goal of 50%) reduction from heritage systems costs
 - To meet commercial competitive market needs, the EELV family has expanded (up to 13 configurations, depending on viewpoint)
 - Cost savings depend on design features and production rate
 - 25% launch cost reduction is less than 4% of government space systems cost
 - Increased reliability -- "better" -- is the most powerful driver of cost savings -- "cheaper"
- Limited government guidance, authority and investment
 - EELV development under "other transaction" funding -- with provision for progress payments against set milestones
 - Government investment currently \$500 million (per contractor)
 - EELV launch service contracts have no provisions (incentives or penalties) for mission success
 - Contracts provide for performance guarantee and mission assurance add-ons as user-funded options

Recommendation -- EELV Cost Pressures

Recommendation

- SECAF direct a reassessment of the EELV contracts for benefit of:
 - Adding provisions (incentives or penalties) for mission success
 - Early use of options for performance guarantee and mission assurance add-ons
 - Examine the benefit of incorporating a cost-plus feature for the reliability confidence building investment

Summary

Overarching Issues

- Mission success in fly-out of current (Atlas, Delta, Titan) systems -approximately \$20B in launch vehicle and spacecraft assets -includes critical systems with no spares
- Transition to the future system -- Evolved Expendable Launch Vehicle (EELV) -- building confidence in launch success

BAR Bottom Lines

- Government ensure industry acts to correct causes of recent failures and improve systems engineering and process discipline
- Government establish clear accountability for mission success for fly-out systems and transition to EELV
- Enhance government industry partnership with needed management, engineering support and emphasis on mission success
- Provide a well-defined, coordinated, disseminated transition plan to EELV
- Government invest to build confidence in EELV reliability with enhancements and increased oversight

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